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Office of Naval Research Final Technical Report
Grant No. N00014-93-1-0068
Principal Investigator: Kristin Rohr, Geological Survey of Canada

Proposal

In the proposal we hypothesized that when the hydrothermal regime in oceanic crust changes from open to closed, the upper crust's physical properties also change significantly as extensive alteration mineralisation fills in the porosity. We tested this hypothesis by interpreting interval velocities in layer 2A in young upper crust 0-4 Ma which undergoes a change in hydrothermal regime at about 1 Ma as sediment covers basement topography. We also interpreted basement velocities at the sediment-basement interface in crust 1-4 Ma. The former represent an average value for the top 600 m while the latter is sensitive to the first 80 - 150 m of crust.

Analyses

Interval velocities were computed at least every kilometer and were more closely spaced when heterogeneity required more analyses. Analysis of basement reflections was restricted to data on crust 1- 4 Ma since these data were collected with a longer streamer than the data on crust 0-1 Ma and recorded critical and post-critical reflections. The inversion of refection coefficients described in Chapman and Rohr (1991) was extended to trace rays through a layer of sediment instead of assuming that the environment consists of two half-spaces. This method can interpret shear velocity and density but requires reflections that are nearly perfect waveforms. We also interpreted the velocity of the top of the crust by mapping the data into tau-p space. This method simply requires finding the basement reflection with the highest amplitude and is more robust.

Results

We learned that interval velocities increase by over 1000 m/s shortly after the hydrothermal regime changes from mostly open to mostly closed (Fig. 1). The increase in velocity is most likely the result of hydrothermal alteration which fills the pore spaces. Velocity at the top of the crust also increases significantly from 2900 m/s to 3800 m/s +/- 500 m/s (Fig. 2). This change is concurrent with the change in interval velocity indicating that alteration must be occurring throughout layer 2A is the result of circulation within the layer and not just as a contact reaction from water in the sediments. Lateral heterogeneity in the altered crust is significant; velocities can change by 1000 m/s over distances of hundreds of metres to kilometers. Poisson's ratios of the altered crust can vary from 0.25 to 0.38 (Fig. 3) and are consistently smaller than Poisson's ratios computed for Pacific crust formed at the same segment of ridge which is still experiencing open hydrrothermal circulation.

Impact of Research

The coincidence of high-quality multi-channel seismic reflection data, heat flow, and pore water

chemistry have provided an unprecedented opportunity to advance our understanding of crustal evolution beyond the simplistic concepts that have heretofore dominated the literature. Research funded by this grant has demonstrated that seismic velocities of oceanic crust can be substantially altered very rapidly. The low-temperature alteration which is well-known to exist had been thought to take 30-60 Ma to occur. This work demonstrated that layer 2A can double in its velocity in a time scale closer to 0.1-0.3Ma and that this can occur in very young crust (1 Ma) when the hydrothermal regime changes. We have further demonstrated that the likely processes responsible for the change are alteration by circulation restricted to layer 2A, the top 600 m of crust.

Two other multi-channel cruises have been funded to look for similar changes in seismic velocity and a German expedition led by Dr. Wilfred Weigel of University of Hamburg is collecting seismic refraction data near the East Pacific Rise also to map early crustal alteration.

The evolution of oceanic crust and the nature of the hydrothermal circulation in this rapidly altering crust will be the subject of several drill holes on an Ocean Drilling Project leg in 1996. Seismic velocity analyses have proved useful in determining first that the crust has been altered and second in choosing specific drilling locations which have been constrained to lie only on the reflection line studied in this grant. This data set should prove a rich resource for comparison to drilling results over the next few years.

Publications to date

Rohr, K.M.M., 1994, Increase of seismic velocities in upper oceanic crust and hydrothermal circulation in the Juan de Fuca plate, Geophysical Research Letters, v.21, p. 2163-2167.

Rohr, K.M.M., Schmidt, U., Lowe, C. and Milkereit, B., 1994, Multi-channel seismic reflection data across the Endeavour Ridge, GSC Open File 2847.

Rohr, K.M.M., 1994, Hydrothermal Alteration of Upper Oceanic Crust, Lithoprobe Seismic Processing Facility Newsletter, v.7, p. 89-91.

Rohr, K.M.M. and Chapman, N.R., 1994, Evolution of Uppermost Oceanic Crust: The Juan de Fuca Plate, EOS 1994 Fall Meeting Supplement, p. 314.

Rohr, K.M.M., 1995, Extent of hydrothermal alteration as interpreted from AVO analyses of reflections from upper oceanic crust, in prep.

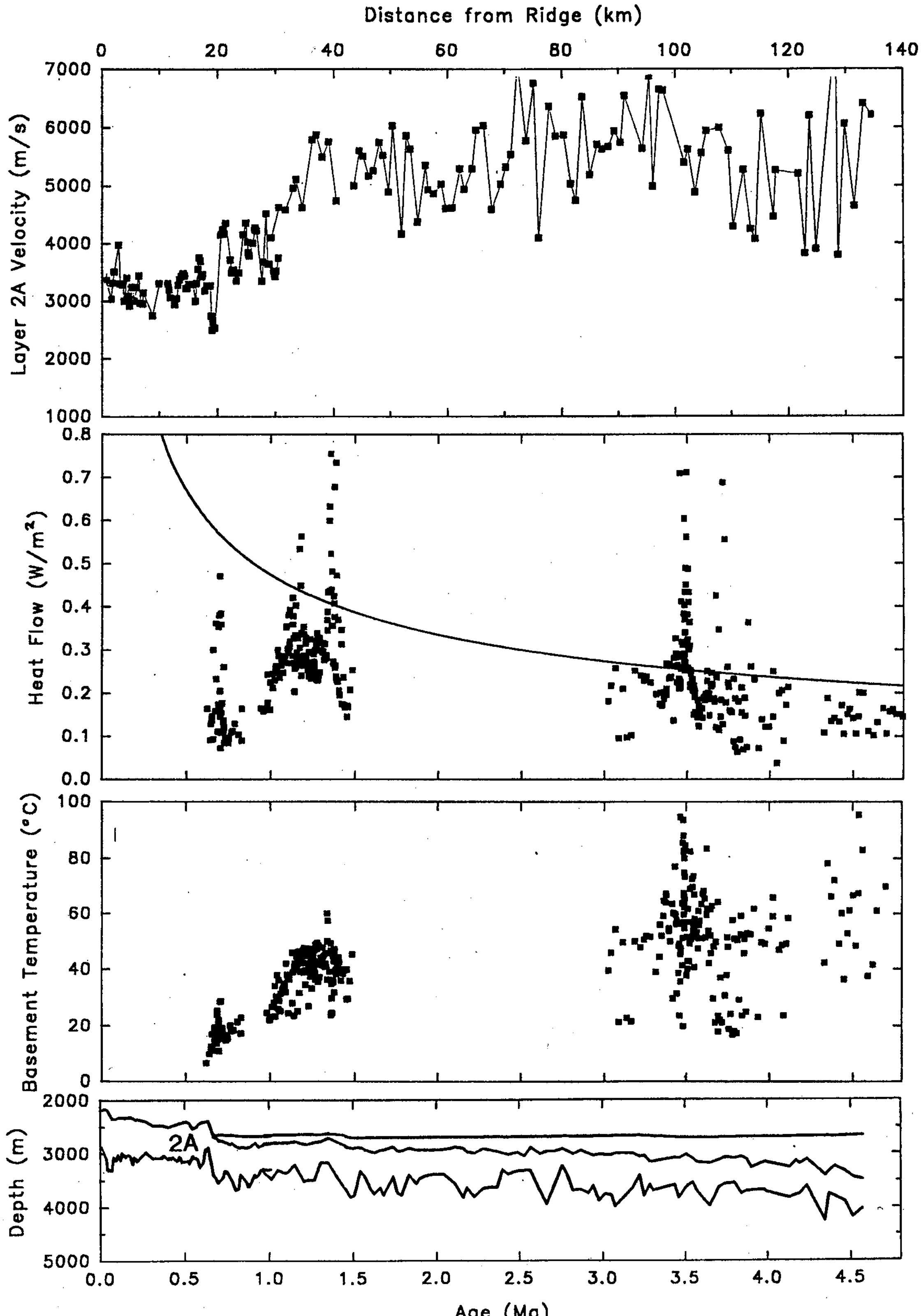
Rohr, K.M.M., in press, Velocity interpretation of critical reflections observed in slant stacks, Lithoprobe Seismic Processing Facility Newsletter.

Figure Captions

Figure 1. Compilation of thermal and seismic properties of layer 2A formed at the Endeavour segment of the Juan de Fuca ridge from 0-4 Ma. A. Interval velocity of layer 2A interpreted from Dix solutions of stacking velocity, These solutions overestimate velocity but increases in velocity from 0.6 to 1.2 MA is significant. B. Heat flow values from Davis et al. (1992) measured in a corridor about the reflection profile. C. Interpreted temperatures in uppermost crust. D. Interpretation of shallow seismic structure of oceanic crust; layer thickness of sediment and 2A were interpreted from Dix solutions of stacking velocities and times.

Figure 2. Velocity vs age for the Juan de Fuca plate. Velocities at the top of basement (circles) reach their plateau at the same location as the Dix interval velocities (diamonds) for layer 2A (Rohr, 1994). Velocities at the top of basement were determined by finding the critical point of the basement reflection in tau-p space. Concomitant rise of interval and basement velocities indicates that alteration is uniform within the layer and not concentrating in the top or bottom. Velocities in Pacific crust formed at the same spreading segment are consistently lower than in the Juan de Fuca crust (squares, Chapman, pers. comm., 1994). Pacific crust is thinly sedimented, still in the open hydrothermal circulation regime and has not been altered as much.

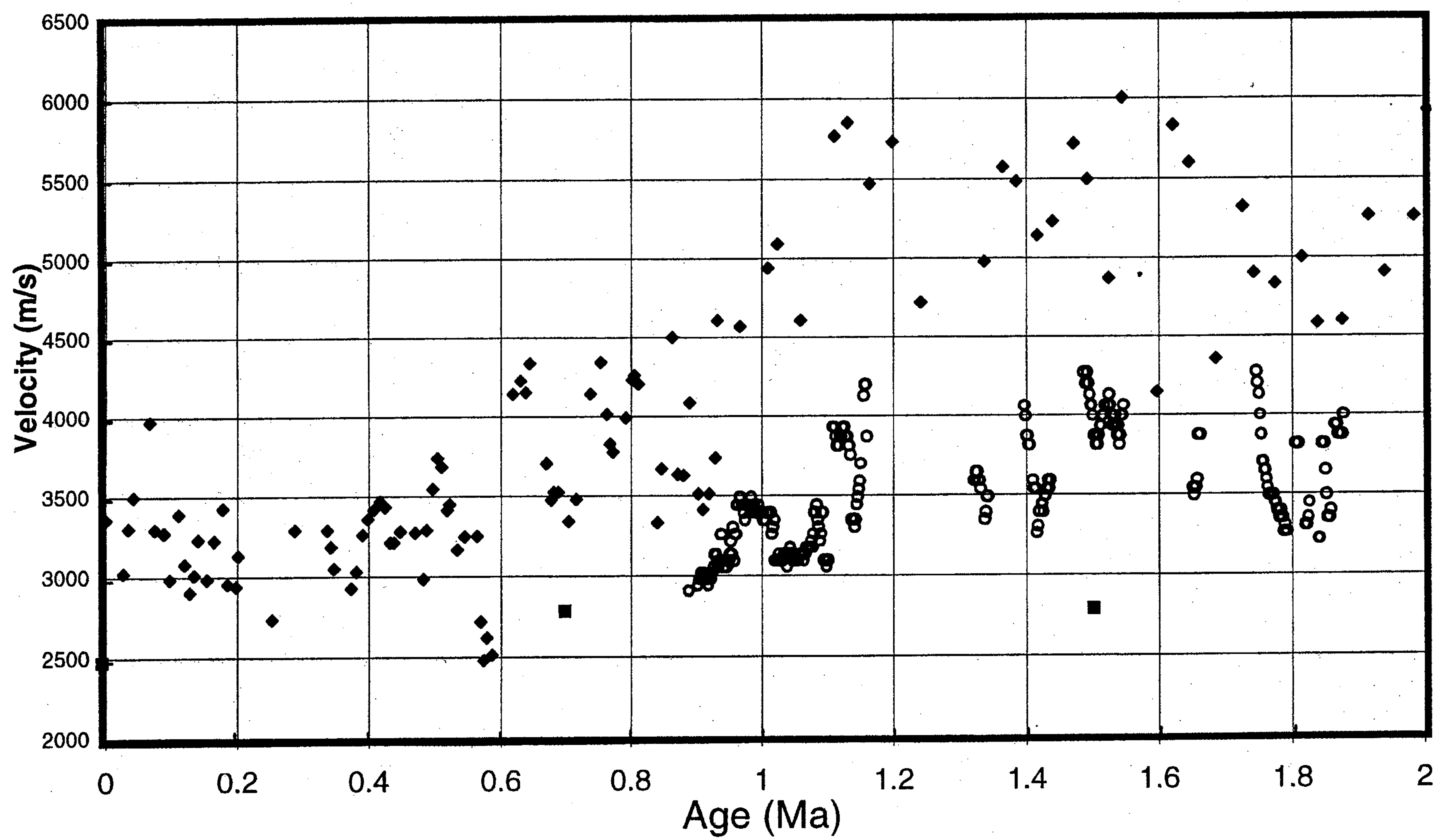
Figure 3. Poissons ratio vs age. Poisson's ratios of Juan de Fuca crust (circles) are lower than those of the thinly sedimented Pacific crust (squares, Capman, pers.comm., 1994) formed at the Endeavour ridge segment. Values for the Juan de Fuca crust were interpreted from time-distance data which were transformed into reflection-coefficient data space and inverted using an adaptation of Chapman and Rohr (1991) method.



Distance from Ridge (km)
0
20
40
60
80
100
120
140
Layer 2A Velocity (m/s)
7000
6000
5000
4000
3000
2000
1000
Heat Flow (W/m²)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Basement Temperature (°C)
100
80
60
40
20
0
Depth (m)
2000
3000
4000
5000
2A
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Age (Ma)

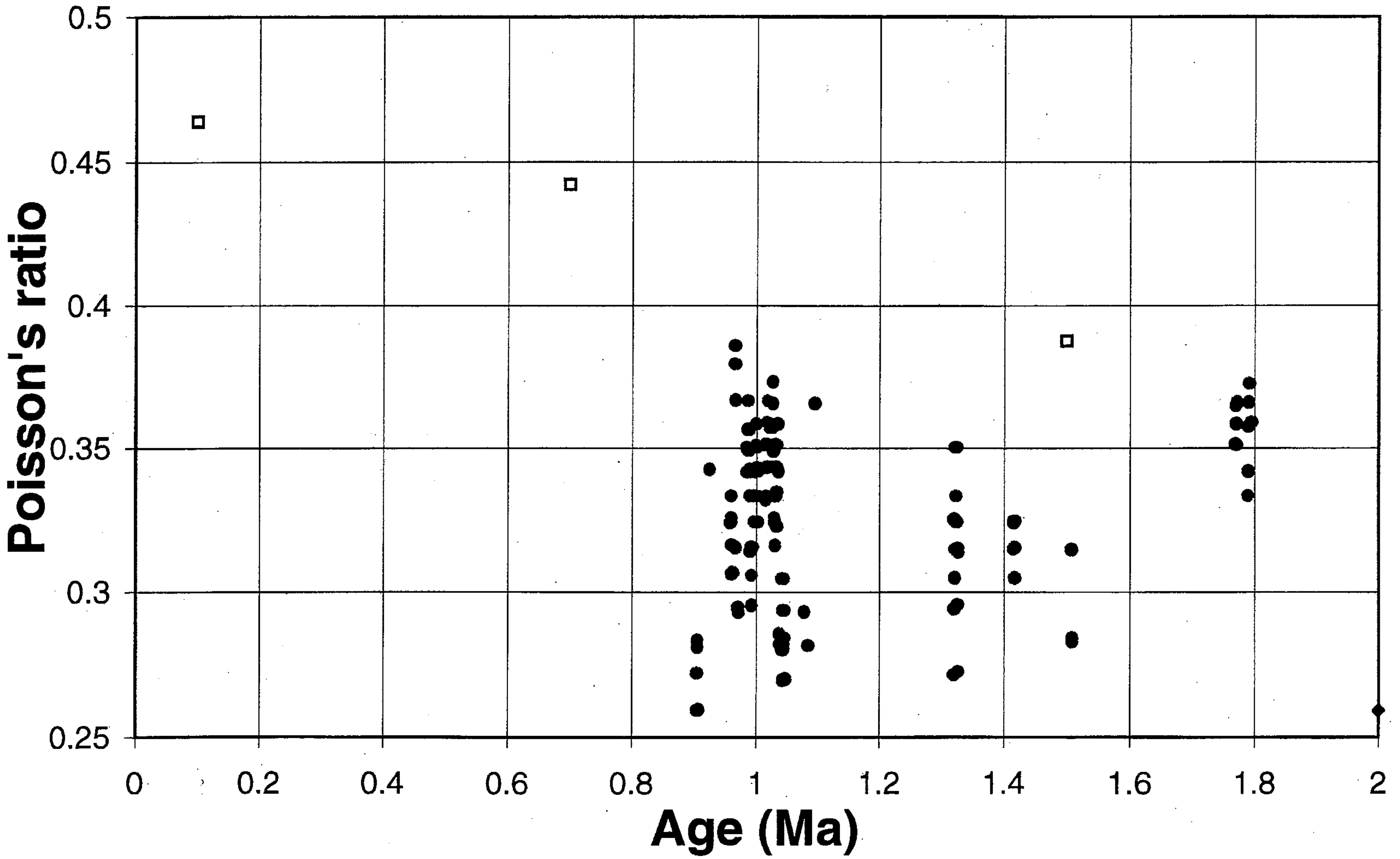
Figure 1.

Figure 2.



6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
Velocity (m/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Age (Ma)

Figure 3.


Poisson's ratio
0.5
0.45
0.4
0.35
0.3
0.25
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Age (Ma)